THE HASHEMITE UNIVERSITY
Faculty of Natural Resources and Environment
Department of Earth Sciences and Environment
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Geological Field Techniques 111201391

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Introduction to field observations at Different scales

3.1 Defining the fieldwork objectives

Fieldwork is undertaken to address particular scientific problems; these should be clearly defined before going into the field. This is because it is very easy, when out in the field and faced by excellent rock exposures, to become distracted by other interesting features or to spend too long on particular aspects. For instance, if the objective of the fieldwork is to determine the orientation, sense and amount of displacement on a series of faults bounding a sedimentary basin then the *only* critical feature of the sedimentary beds required is knowledge of the stratigraphy to determine the amount of displacement across the faults. On the other hand if the objective of the fieldwork is to produce a graphic log of the succession then the details of any later structural movement are not required, except of course to be able to place the beds in stratigraphic order and to compensate for any displacement (Table 3.1).

Table 3.1 Common objectives for completing geological fieldwork and cross references

Overall objective	Main data to collect
Gain a general insight into the geology of an area	Lithology, structural and age data from selected representative exposures
Construct the geological history of an area	Relative age data and basic geological information on each of the major units in the area and their relationship to each other
Produce a geological map	Lithology and structural information from as many exposures as possible within the time and resources available
Determine the sedimentary depositional environment	Graphic logging of both sedimentary and palaeontological features, sketches and facies analysis
Make a record of a period of climate change	Graphic logging with particular emphasis on the collection of data that are indicative of climatic conditions; high-resolution relative dating of the succession and collection of high-resolution samples for proxy analysis (e.g. carbon isotopes)
Determine the sea-level history over a period of geological time	Graphic logging along a proximal to distal transect; application of the principles of sequence stratigraphy
Biostratigraphy	Collect zonal significant body fossils systematically through the stratigraphy or samples for microfossil analysis
Determine the level of an extinction event	Record the finds and hence stratigraphic ranges of the fossils
Determine the nature and order of a series of igneous events	Determine the overall mineralogy and rock fabric including the presence/absence and composition of phenocrysts, and size, shape and fabric of any vesicles; examine the cross-cutting and chilling relationships
Monitor the activity of an active volcano	Seismic, gas emission, gravity, thermal and observational data
Collect samples for geochemical analysis in order to understand Earth processes	Position of the exposures where samples were collected from and features of the rock body
Locate mineral resources	Mapping and collection of samples for analysis
Record the deformation history of an area	Mapping, structural measurements, cross-sections and stereonets
Prediction and monitoring of earthquakes	Mapping and geophysical measurements

3.2 Scale of observation, where to start and basic measurements

Geological observations need to be made at a range of scales. Start at the large regional scale: this will provide the overall context. Then, consider the whole exposure, followed by units within the exposure and finally focus down to the hand - specimen scale.

3.2.1 Regional context

Before starting any fieldwork it is essential to research the regional setting, context and previous work. Aside from books, scientific papers and maps on the regional geology, web – based satellite image display systems such as Google Earth provide an easy way of investigating the general lie of the land and making preliminary observations on a large spatial scale and in some cases in more detail. A desktop regional study may be used to gather information on: access to the field locality and within it; the overall topography; the type and location of potential exposures; the general structure and strike of the beds.

3.2.2 Whole exposure

Arriving at a large exposure for the first time can be both exciting and daunting. It is often difficult to know where to start so, check whether the exposure is safe and then walk around and view it from different angles before making a decision. One way to tackle a large exposure with different rock types and features is to first of all divide the exposure into 'units' based upon obvious features such as changes in colour and weathering characteristics. In most instances you are looking for somewhere between about 2 and 10 units (Figure 3.1), any more than this and it is hard to assimilate. If you have more than about 10 units you should try to group them together. Decide from a distance what the main characteristics of these units are and consider making a sketch to show these characteristics and their relationship to each other before completing more detailed observations close up.

Your preliminary observations of the large - scale features in the exposure should include the following.

• *Nature of the contacts:* Note whether the contacts are gradational (e.g. colour change between units 2 and 3 and within unit 2, Figure 3.1 d) or sharp (e.g. contact between units 1 and 2, Figures 3.1 a and 3.1 c) and whether they are planar (e.g. Figures 3.1 a and 3.1 c) or irregular (e.g. contact between units 2 and 3, Figure 3.1 b and between units 1 and 2, Figure 3.1 d). In the case of irregular contacts note the geometry.

• *Lateral changes in thickness:* Note the position and amount of any changes. These might relate to processes such as erosion, faulting, fluvial or submarine channels, thinning of a dyke or sill, changes in depositional conditions of sedimentary and extrusive rocks. Note which units change in thickness (e.g. unit 4, Figure 3.1 b) and which are cut out (e.g. unit 3, Figure 3.1 b).

• *Cross - cutting relationships:* Look for cross - cutting. For instance an igneous body cutting through older strata, erosional down cutting or an angular unconformity (e.g. Figures 3.1 b and 3.1 d).

• *Evidence of displacement and deformation:* Look for folding and faults (e.g. Figure 3.1 a). Note any general trends in orientation angles and scale.

• *Angular unconformities:* Look for a change in the rock type associated with a change in the bedding orientation. The large - scale weathering features of the units you are looking for are:

• whether any of the units stick out from the cliff or weather back (e.g. Figure 3.1 c, unit 5 compared with unit 4);

• whether any of the units are massive, i.e. structureless (Figure 3.1 b, units 1, 2 and 4);

• whether any of the units break into slabs or are crumbly (Figure 3.1 c, units 1 – 3);

• whether there any notable changes in vegetation that may be associated with changes in lithology (e.g. Figure 3.1 c units 1 and 4 are supporting trees), i.e. depending on mineralogy and permeability different rock types support different plants or have different moisture contents;

• whether the change in weathering matches with a change in colour, which together imply a change in lithology.

Once you have defined the main units, examine each one, in turn, close up, collecting the data that are appropriate to the objectives of the fieldwork. Some exposure surfaces do not reveal much, whereas other surfaces (e.g. where weathering has etched out the bedding or a fabric) may be more revealing. Don’t worry if you cannot identify a rock type or geological feature straight away. If possible examine the rock or features in different parts of the exposure (e.g. natural vs. quarried, stream cut vs. wind etched) and its relationship to enclosing rocks or other features, its nature and identity may become apparent over the course of time. If not, record the features carefully in your notebook and with a camera and use the literature, or ask another geologist, to help identify them.

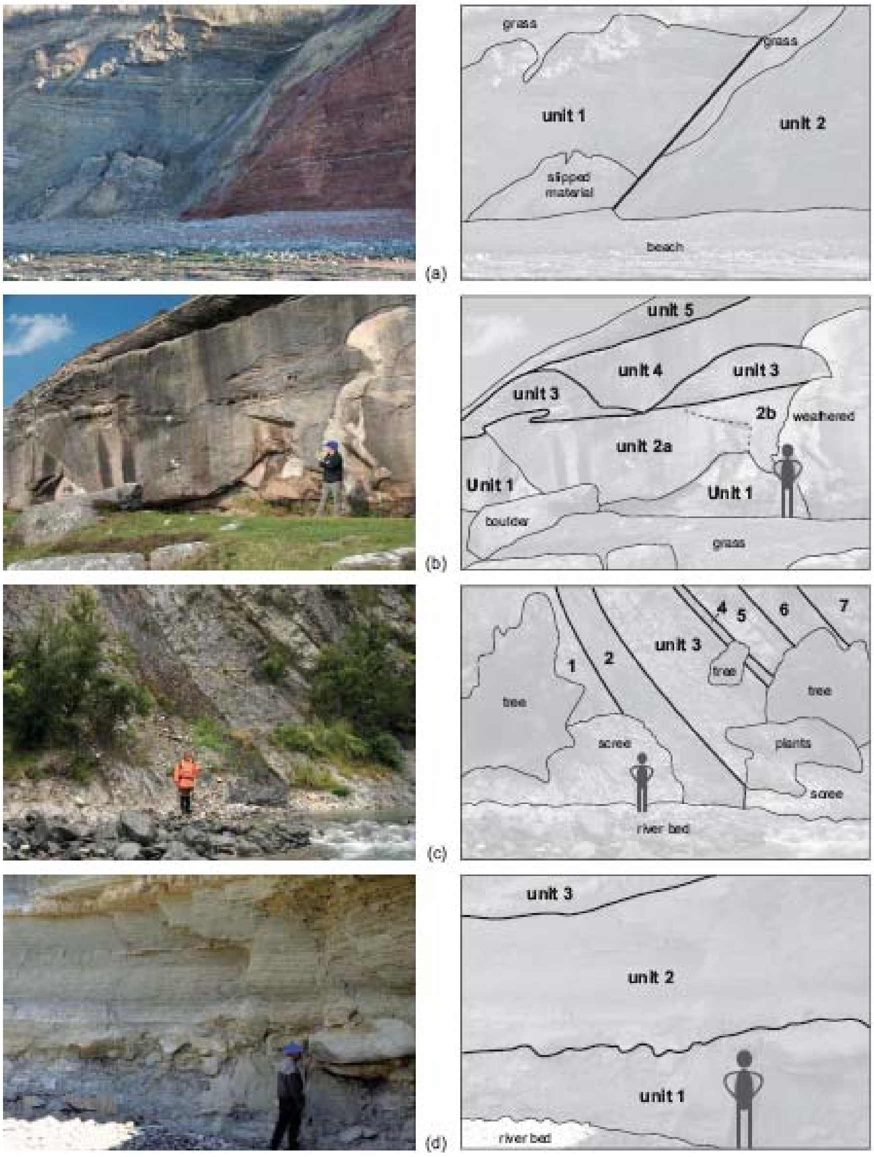


Figure 3.1 Four photographs and accompanying line drawings of different exposures showing how they might be divided into major units for recording and further examination. (a) Jurassic strata faulted against Triassic strata at Blue Anchor, Somerset, UK (height of cliff *c* . 10 m). (b) Carboniferous strata at Bowden Dors, Northumberland, UK. (c) Eocene strata exposed in the Clarence Valley, South Island, New Zealand. (d) Cenozoic strata at Choirokitia gorge, Cyprus. (a – d: Angela L. Coe, The Open University, UK.)

3.2.3 Hand specimens

When you select a loose sample, or an area of the unit to examine closely, check that it is representative of the unit being examined and that it has at least one very fresh surface. Loose specimens can be hammered to obtain a fresh surface. Only hammer off a small chip from an exposure if it is absolutely necessary and first ask yourself whether hammering will deface an exposure badly. To select a representative part you should consider the main features of the unit. For instance if 80% of the unit is sandstone and the other 20% is a muddy sandstone then ensure that you have a specimen of the main sandstone. Once you have examined the fresh surface you should supplement your observations by examining the weathered surface. In some rocks, for instance limestones and metamorphic rocks, differential weathering processes leave some minerals or grains sticking out of the main surface where they are easier to identify.
The questions and notes overleaf provide some points to consider when deciding whether the rock is igneous, metamorphic or sedimentary. As well as the composition and texture of the rock, its context should provide a good indication of the category that the rock type belongs to. Appendix provides an overview of the checklists, rock – forming mineral tables and textural and classification diagrams provided elsewhere. Commonly several of the units within an exposure are related to each other, so once you have described one hand specimen you should consider if it is possible to describe the others by simply noting differences between them. Often in sedimentary successions, but also with igneous bodies, it is the changes and differences between the units that provide clues about how the processes within the succession have changed.

Some questions to think about when deciding whether a rock is igneous, metamorphic or sedimentary:

• Is the rock made up of interlocking crystals, or made up of crystals in a fine - grained groundmass, or made up of grains within a matrix? If it is composed of grains then it is likely to be a siliciclastic rock or a carbonate but it could also be a pyroclastic rock. If it is crystalline then it could be igneous, metamorphic or one of the less common sedimentary rocks such as an evaporite or recrystallized limestone.

• What are the major minerals in the rock? There is only a limited range of minerals in sedimentary rocks and certain minerals are diagnostic of metamorphic conditions.

• Does the rock body show layering? In many cases this is bedding and it indicates sedimentary rocks, lava flows or pyroclastic rocks. Be aware though that a few metamorphic and plutonic rocks can also show layering which may be mistaken for bedding.

• What is the geometry of the rock body? Both igneous and sedimentary rocks can form dykes and sills but these are relatively uncommon in sedimentary rocks.

• What is the overall context of the rock body? Metamorphic rocks either form distinct, concentric zones around an igneous body if they are due to contact metamorphism, or more extensive outcrops if they were formed through regional metamorphism.

• Does the rock show a mineral foliation? If it does it is probably metamorphic, although some igneous rocks show such fabrics.

• Does the rock show distinct cooling joints? These form only in igneous rocks, although they can extend into the adjacent country rock.

• Fossils are absent from igneous rocks except for the occasional occurrence in pyroclastic deposits. Fossils are only rarely preserved in low - grade metamorphic rocks and are not found in high - grade metamorphic rocks.

• More complex bedding structures such as cross -stratification and ripples are confi ned to sedimentary and pyroclastic rocks.

• Sedimentary rocks show a range of porosities whereasplutonic igneous and metamorphic rocks have a very low porosity.

• Metamorphic and igneous rocks have a higher density than most sedimentary rocks.

4.1 Introduction: The purpose of field notes

Designing and using a good field notebook layout adapted to suit *your* needs and style will enable you to be systematic in the notes that you take. This will help ensure that you do not forget major components and that the information you collect is much more accessible and therefore more readily useable

4.2 General tips

• *Cross referencing:* Number the pages of your notebook; this will allow you to cross reference, indicate where notes and figures might be continued, provide references to other documents and produce a list of contents for ease of access to information at a later date.

• *Use of space:* Space your notes out so that there is room to add further notes if you revisit the locality or to record the location of samples. Extra space is also helpful if you wish to add interpretation later on, or a discussion that you have had with colleagues about the data at a later stage. Space also makes the notes easier to follow.

• *Organization:* Use headings and subheadings as they make the notes much easier to find. Devise a system to show the hierarchy of these headings. For instance use a box around the main heading and an underline for the others. Record ideas and points of interpretation in a different manner, for instance in a separate column or in a 'cloud'. Another tip is to use a colored pencil/waterproof pen to pick out particular notes that are important to the task in hand: for instance, sample numbers or locality numbers or photographs or strike and dip data. Information can also be organized by ordering it into columns.

4.3 Field sketches: A picture is worth a thousand words

Sketches form a vital part of all geological field notebooks. They include: diagrams of cliffs or quarry faces; sketches of individual features such as a fossil, mineral or sedimentary structure; sketch maps; cross - sections; and sketches showing ideas for interpretation. Sketches are one of the best ways of recording and conveying geological information. This is for two reasons: (1) <u>They provide a shorthand means of conveying information in an easily accessible form</u>. For example, it is much quicker to draw the form of an irregular contact between two beds than to describe it. Because geology is mostly about the relationship between different rock bodies and their three – dimensional geometries, irregular shapes and contacts are common, and it is much easier to convey this in detail in a figure than it is in words. (2) <u>The very act of producing a good sketch involves carefully observing the features, units and the relationship between all of them</u>. If executed properly, sketches can convey much more of the key geological information than a photograph because the author has to pick out the

important geological features that relate to the objective of the fieldwork more clearly, add labels to show where other data have come from,
and add a certain amount of interpretation. It is worth bearing in mind that the human eye is much more sophisticated than any camera.

• *Space:* Allow plenty of space in your notebook for the sketch so that there is room to add labels summarizing observations, scale and orientation, detailed drawings of pertinent parts (insets), cross references to later sketches or other written notes, and labels summarizing points of interpretation. It is also much easier to sketch at a larger scale; if you are not good at sketching it may be tempting to push the sketch into one corner of a page of the notebook but this is making it far more difficult for yourself. So, take your time and use a whole page or even two facing pages for the sketch and labels. Don’t spoil a good sketch with too many labels though or place labels on the sketch so that
they obscure parts of it.

• *Scale:* All sketches should include a scale. How accurate the scale of the sketch is will depend on the purpose of the fieldwork. However, it is important to get the features into proportion. For sketches of cliffs, hillsides, etc., once you have established a scale for a small portion (e.g. from the height of a person or size of a vehicle) use your thumb held at arm ’ s length to estimate the scale for the remainder of the sketch.

• *Orientation:* All sketches should include an orientation relative to north and a clear indication as to whether it is a plan view, oblique view or cross - section (e.g. cliff). The simplest and most straightforward way of adding an orientation is to use a north arrow for any plan views and to label the ends of cross - sections with the nearest compass points, e.g. NW – SE or NNW – SSE. Alternatively, you can label your viewpoint to the centre of the sketch, e.g. looking due southeast or looking towards 135 ° . The latter method is popular for views of oblique surfaces but is not recommended for cliff sections because it is not as clear.

• *Angles and geometry:* Boundaries between units and features within units (e.g. cross - stratification or folding) are best shown at approximately the correct angle of dip. This will not only make the sketch look more realistic, it will be more accurate and make the features easier to identify. In general people tend to exaggerate angles (i.e. make them steeper). A simple technique for obtaining a good estimate of the angle is to put your compass - clinometer into the clinometer mode and then holding the compass - clinometer at arm ’ s length with Notebook the long edge at the same angle as the features whose dip you are trying to estimate, read off the apparent dip.

• *Inset boxes for detail:* In some cases the geological feature repeats itself on the small scale, or there is one particular part of the cliff that you want to collect data on in more detail. So rather than putting the detail in for the entire cliff face one useful technique is to draw the main features on the sketch and then add a box to indicate the area where a photograph has been taken or a more detailed sketch has been constructed (Figures 4.4). This also enables you to draw the detailed part at a larger scale if appropriate.

• *Colour:* A green colored pencil can be useful for showing the vegetation and clearly separates it from the geological part of the sketch (Figure 4.4). A red or blue coloured pencil is useful for cross references, particular items or key features.

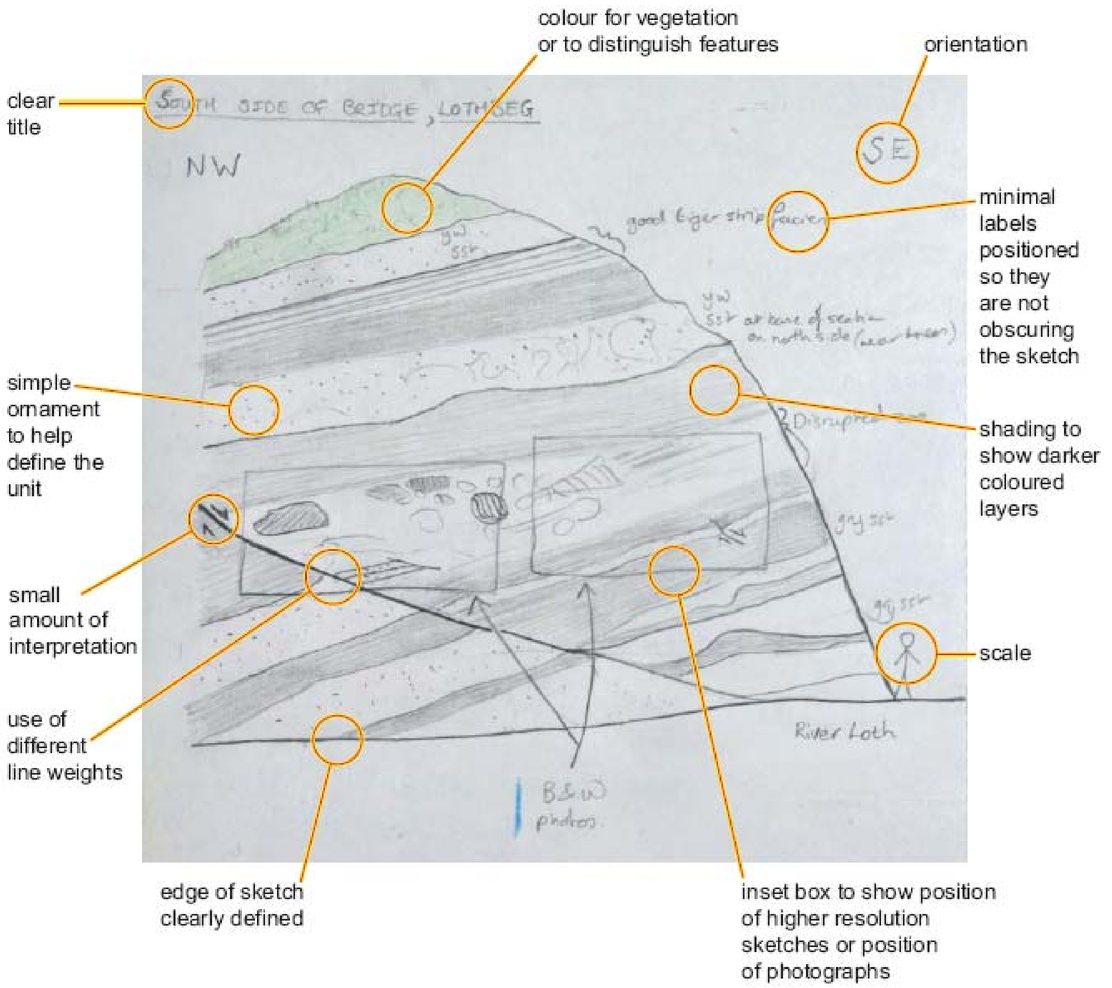


Figure 4.4 An annotated example of a field sketch showing some of the key features that can usefully be included in a sketch. This sketch is of Kimmeridgian rocks exposed in northeast Scotland. (Notebook of Angela L. Coe, The Open University, UK.)

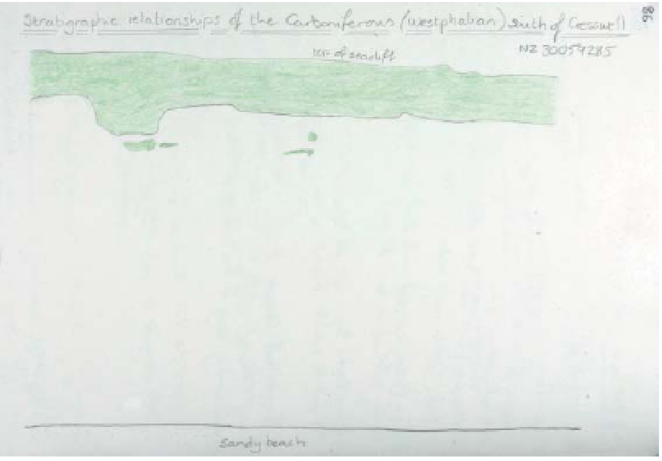
4.4 Sketches of exposures

Sketches of whole or representative parts of, exposures such as sea - cliffs, road cuts and quarry faces are commonly used to observe and show one or more of the following:

- The main units and the geometric relationship(s) between them;
- Large - scale (meters to tens of meters) structures such as folds, faults and angular unconformities;
- The position of more detailed measurements (e.g. samples or a graphic log so that the exact location can be easily relocated. In most instances it is best to take up an entire page, or even two facing pages, of a hardcopy notebook when constructing a sketch of a cliff or quarry face. Also consider the orientation of the notebook; <u>would the subject matter be best captured with the notebook page orientated landscape (i.e. wider than it is taller) or portrait (i.e. taller than it is wider)? Long cliff faces are usually best landscape whereas a vertical profile through a cliff might be better portrait</u>. Figure 4.5 b – f shows how you might build up a sketch of the cliff shown as a photograph in Figure 4.5 a. While these instructions are divided into suggested steps it may be necessary to amend the order depending on the subject matter, or go back to a previous step to add or amend the detail. The aim of the exercise in the case of Figure 4.5 is to summarize the main rock units and the relationship(s) between them.

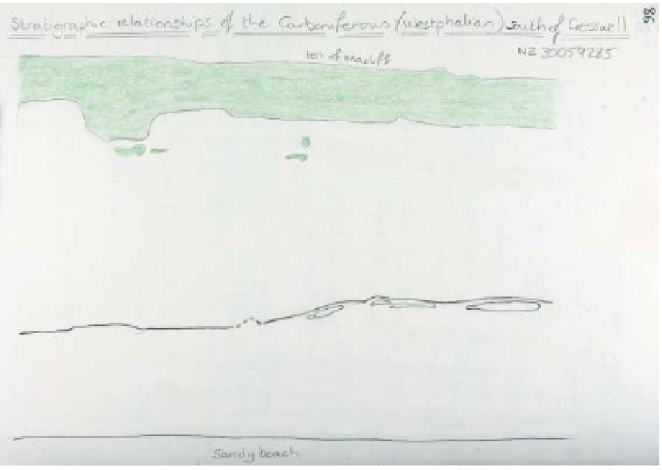
1. Assess the units

Spend some time looking at the exposure and deciding how many units there are (. Look for any major features such as cross-cutting relationships or displacements. Choose a representative part of the cliff to sketch (shown by the yellow box in this case).



2. Draw the outline

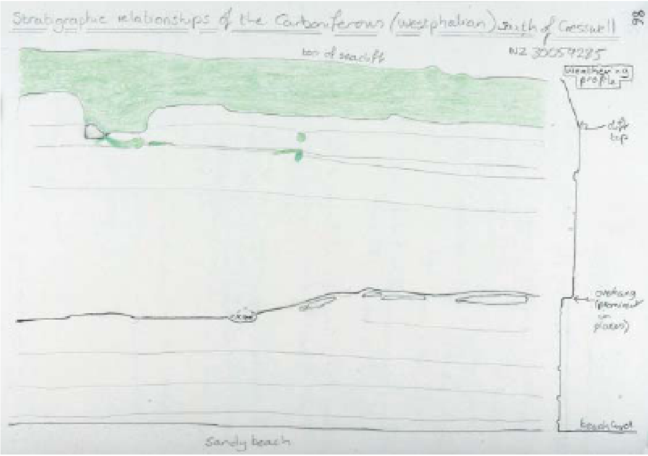
Decide on the best orientation of your notebook for the sketch (in this case landscape). Put a title/caption at the top of the page, detailing the subject of the sketch and the aims. Draw the outline of the area first, i.e. the bottom and top of the cliff, and extend the sketch laterally to the edge of the chosen area. If there are areas of vegetation add at least the main ones as points of reference.



3. Draw the major geological boundaries

Draw the major boundaries between the units. As you sketch in the boundaries pay particular attention to whether the boundaries are sharp, or gradational, undulatory or planar. Use a thick, bold line for where the boundary is sharp and distinctive, and a medium density line for those that are gradational. Use your compass-clinometer to estimate apparent angles (Section 4.3.1) and your thumb held up in front of you at arm's length to estimate the relative thicknesses. Ensure that the boundaries between the units are continuous for their entire length; if the boundary is obscured by vegetation or slipped material mark this in.

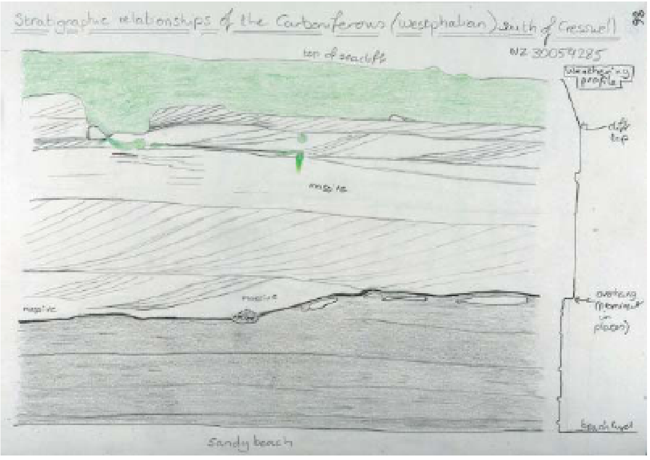
Figure 4.5 Photograph of Carboniferous-age strata near Cresswell, Northumberland, UK and series of sketches showing how a field sketch of this exposure might be gradually constructed. Note that features of no interest such as the large cracks have been ignored because they would detract from the geological features of interest.



4. Draw the boundaries of any subunits and a weathering profile

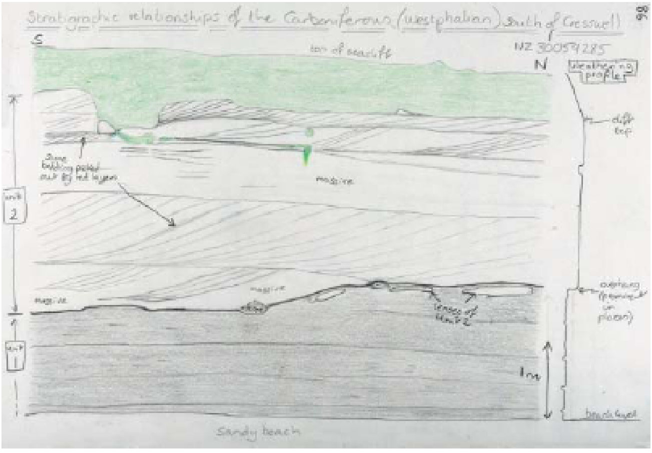
Where there is differential weathering of the rock units it can be helpful at this stage to draw a weathering profile at the side of the sketch that is directly related to each of the units. This can be used to relocate your position on the sketch particularly if there are many units.

Draw in the boundaries of any subunits using lines of appropriate weight and thickness. If appropriate, add other features such as scree, and further details on reference points such as vegetation to help you locate the different parts of the sketch but ensure that these do not detract from the main part of the sketch.



5. Sketch the detail within each of the units

Observe each of the units in turn and add the following: shading for any darker coloured units (using different densities of shading as appropriate); any detail within each of the units/subunits using thin lines, e.g. thinner beds, sedimentary structures, folds, etc. Ensure that as you add to the sketch the boundaries between the main units remain clearly defined. If for part of the sketch there are features that are hard to distinguish, or you do not have time to add the detail, label the sketch accordingly (e.g. features not shown, massive).

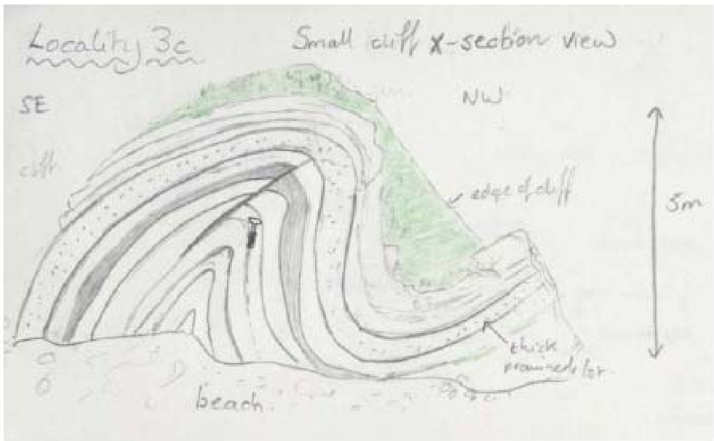


6. Add the finishing touches

Add a scale, orientation and number/name the units so that you can refer to each of them in your further notes. Complete a detailed sketch of any key parts and mark how these relate to your main sketch.

Figure 4.5 *Continued* The rock face is depicted in the sketch as if it has been projected on to a two-dimensional vertical plane. (Notebook of Angela L. Coe, The Open University, UK.)

(a)



(b)

Figure 4.6 (a) Photograph and (b) sketch of a fold near Berwick-upon-Tweed, UK illustrating the technique of tracing several key beds through the structure in order to illustrate its overall form. (Notebook and photograph of Angela L. Coe, The Open University, UK.)

A few other tips:

• If the exposure is composed of many thin beds with no really distinct units, concentrate on one or two beds and use them to depict the overall structure in the cliff (e.g. Figure 4.6).

• If the face is structurally complex you may have more than one possible interpretation. Show this by either completing more than one sketch, or completing a sketch and adding several small cartoons to show the different interpretations or using different colors to depict alternative interpretations.

• Use different line weights to distinguish between distinct and gradational boundaries. Use shading to pick out darker coloured units.

• Do not try and draw the three - dimensional nature of the face. This will make it very complex. Imagine instead that the beds are projected onto a flat plane. If necessary draw a sketch map to relate different two - dimensional faces to each other.

• If the sketch is to cover a laterally extensive area add a horizontal scale and consider breaking the sketch into scaled panels.

4.5 Sketching meter – and centimeter - scale features

All geological features occur in three dimensions, whether they are due to rock deformation, sedimentary processes or intrusion processes. Whilst a small minority of people are capable of drawing clearly in three dimensions, most of us are not. For some features such as faults and bedding a two - dimensional representation is sufficient.
However, where more difficult three - dimensional features need to be recorded such as folds or sedimentary structures there are two simple solutions depending on the feature being recorded.

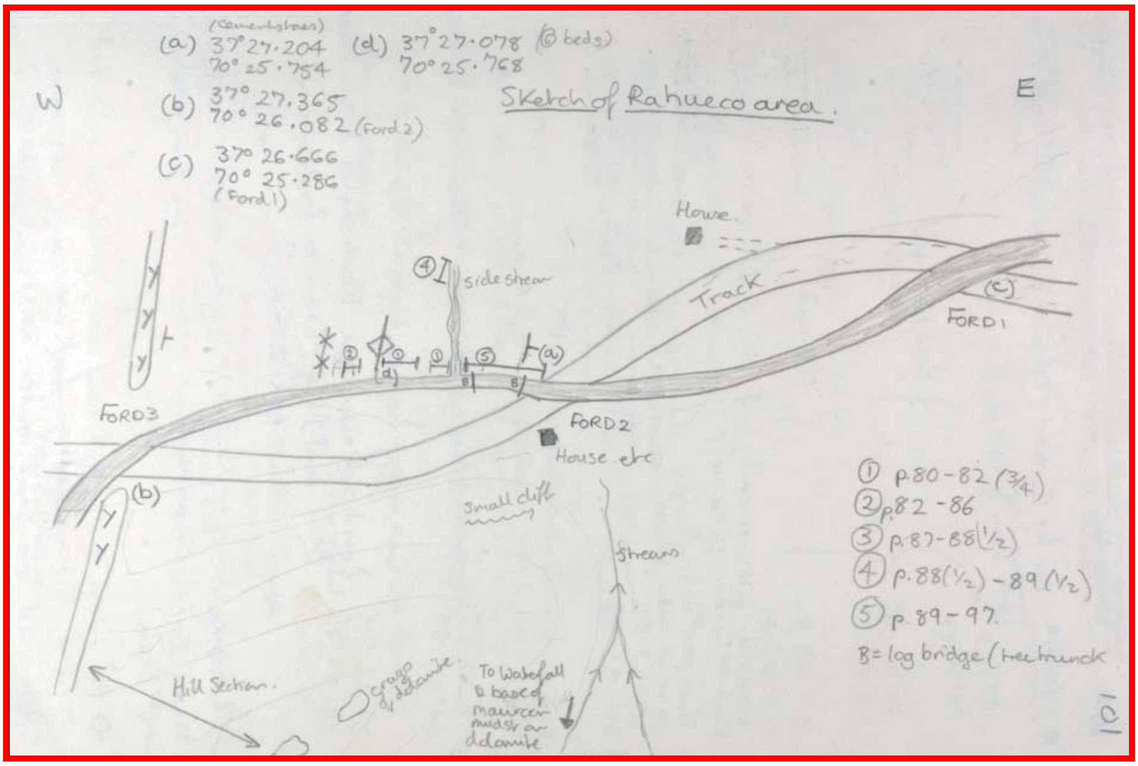
• Draw two or three sketches of faces that are approximately at right angles to each other to illustrate the three - dimensional characteristics. It is important in this case to choose the most representative faces.

• Record the features as a small - scale map and cross – section (for instance the anticlines and synclines.

Another useful technique when sketching structures is to ensure that the geometries are drawn at the correct angle. This means checking the apparent angle of any dipping surfaces and drawing them to within about 5° as well as showing the geometric relationship between the different parts correctly. For instance in cross - stratified deposits the beds generally dip at between about 10° and 25° and never higher than 40° ; the individual layers in cross - sets do not cross - cut each other; and the base of the beds run in tangentially to a bottom surface that represents true bedding. Fossils are often best also recorded with photographs. Sketching has the advantage of making the geologist observe the features, but fossils are often so complex that a photograph is quicker and easier. If the fossil is partly obscured or has a complex three - dimensional form (e.g. some burrows), or you need to show the overall context, then sketching may also be necessary to show the overall form and how the different parts are related . This ensures that you have a record of the interpretation of how the different parts fit together to enable the photographs to be put into context.

4.6 Sketch maps

Sketch maps can be constructed to show areas of interest at a high spatial resolution so that the area can be relocated at a later date, or to remind you how the different data sets that you collected are related laterally. They can also be used to depict geological relationships schematically that cannot be shown on a single sketch. Sketch maps need only to be roughly to scale; they should, however, include an approximate scale and a north arrow. You should include sufficient topographical features, such as the edge of a cliff face or buildings or the sea, as well as the access route in order to put the specific geological material into context. Remember that there is no point in reproducing detailed topographical maps that are already published and which you can annotate instead. The sketch map should add something new and useful. If you need to produce an accurate geological map then your recordings should be plotted precisely on a topographic field map or aerial photograph. Occasionally the hard - copy accurate base map is not at a large enough scale and, in these cases, it may be useful to draw an expanded map in your notebook and to add other topographical features.



Examples of sketch map constructed to show the position of important geological information. River section in Argentina to show the location of a series of graphic logs. Note the GPS readings for key topographical features (a, b, c, etc.) and cross references to notebook pages where the graphic logging notes are located

4.7 Written notes: Recording data, ideas and interpretation

4.7.1 Notes recording data and observations

Written notes on the raw scientific data and observations that you collect can range from rock and fossil descriptions, to structural measurements, to more detailed notes on the relationship between rock bodies (Figure 4.11). These observations and data should be short notes rather than full sentences because these take longer to write and can detract from the main point. Bullet points, clear subheadings or numbered lists are a useful style to adopt for field notes as this encourages brevity and makes it easier to assimilate the individual points. If a lot of numerical information is being collected it is best presented in the form of a table. This will make it easier to assess at a glance whether all the necessary information has been recorded, and also aids its conversion into an electronic format. It can also be useful to develop your own abbreviations for features that are commonly used. Given that the constraints on fieldwork tend to change frequently it is useful to regularly review the progress made and construct a list of further tasks (Figure 4.12 a and b). It is also common to compile a summary list of the samples collected (Figure 4.12 c) and/or photographs taken (Figure 4.2 b). This helps to ensure that each sample has a unique number, places the information in a readily accessible form and allows other information to be added (e.g. grid references; Figure 4.12 b).

4.7.2 Notes recording interpretation, discussion and ideas

As well as new data, you should also record ideas, possible interpretations and questions when you are in the field to help you test competing theories. This might be in the form of a list, a figure, or even a series of cartoons illustrating a geological history. It is often useful to record the whole thought process so that you can reanalyze this at a later stage. Frequently, when collecting field data, different possible interpretations come to mind because you are totally immersed in the information; this is particularly true when working with a field partner or as part of a team. The interpretation and ideas that you record should not just be the 'perceived correct answer or that of the group leader ' , because new data may change the interpretation. Also the recording of other ideas and interpretation can help to confirm which of several hypotheses is correct and determine what other observations need to be made. Ensure that you separate data from interpretation, in addition to noting the origin of the interpretation (Figure 4.13).

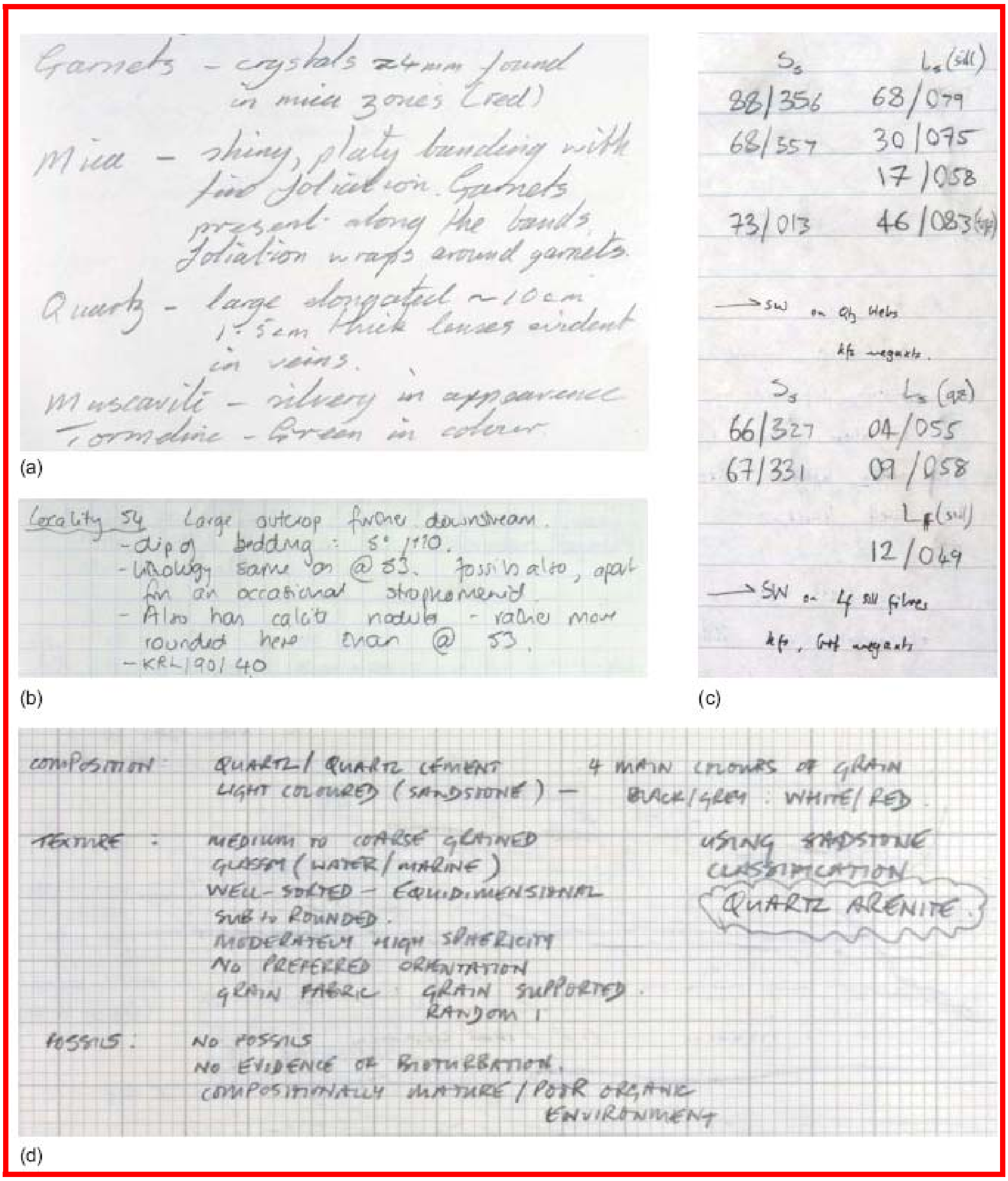
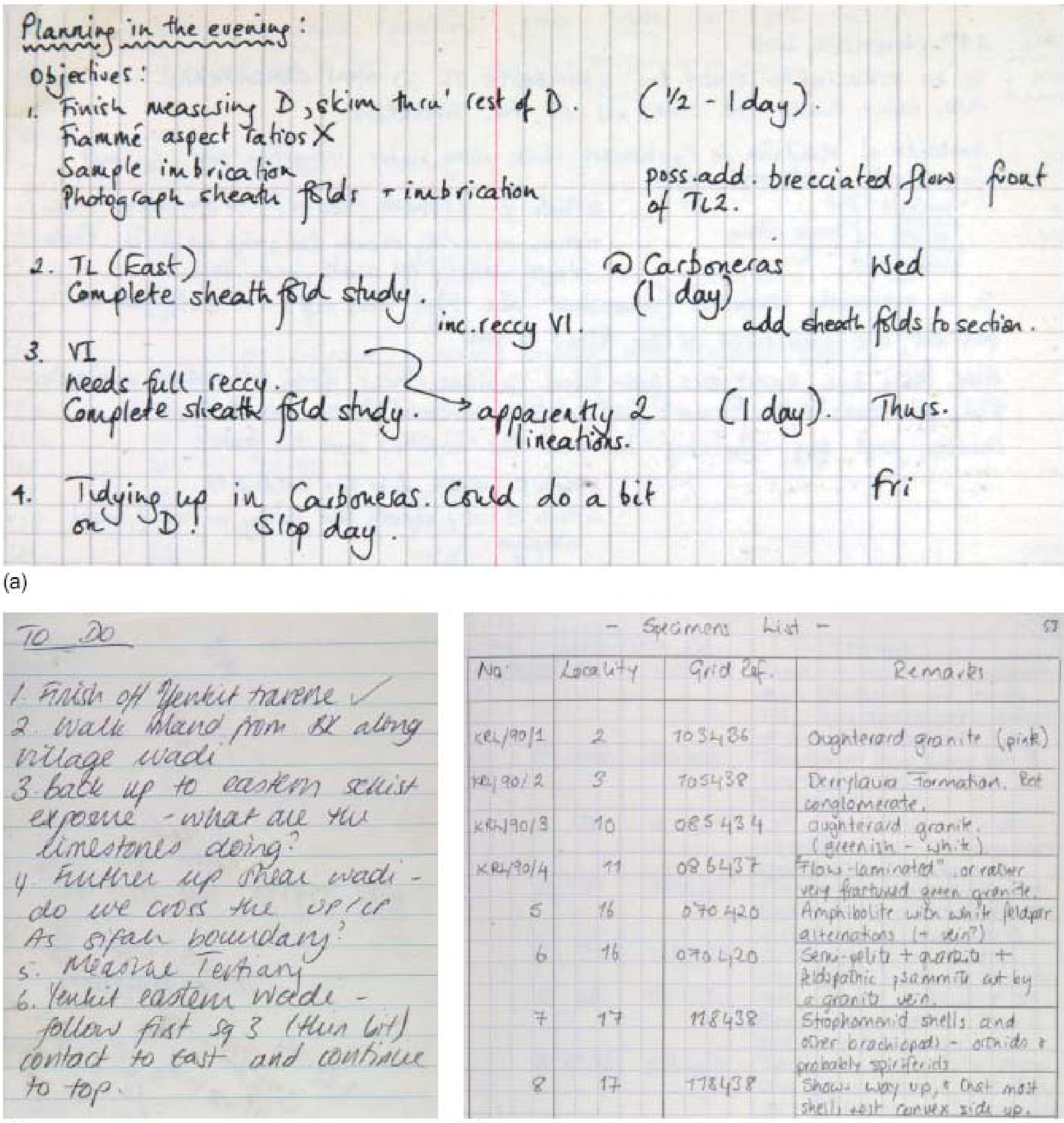


Figure 4.11 Extracts from field notebooks showing examples of written data styles. In all cases the data are clearly laid out and easy to find. (a) List of the main minerals in an igneous rock and the characteristics of each of the minerals. (Notebook of Paul Temple, Open University student.) (b) Main observations at one locality in an area that was being mapped. (Notebook of Kate Bradshaw, The Open University, UK.) (c) Ordered and systematically recorded structural data of both planes and linear features with the dip recorded as a two – digit number and the strike as a three - digit number. *Note:* S_s = main foliation, L_s = main stretching lineation, L_f = fault lineation; the other abbreviations refer to minerals



Planning in the evening:
Objectives:
1. Finish measuring D, skim thru' rest of D. (½ - 1 day).
Fiammé aspect ratios X
Sample imbrication
Photograph sheath folds + imbrication
poss. add. brecciated flow front of TL2.
2. TL (East) @ Carboneras Wed
Complete sheath fold study. inc. reccy VI. (1 day) add sheath folds to section.
3. VI
needs full reccy.
Complete sheath fold study. → apparently 2 lineations. (1 day). Thurs.
4. Tidying up in Carboneras. Could do a bit on D! Slop day. Fri

(a)

TO DO
1. Finish off Yenkit traverse ✓
2. Walk inland from BK along village wadi
3. back up to eastern schist exposure - what are the limestones doing?
4. Further up shear wadi - do we cross the upper As ofan boundary?
5. Measure Tertiary
6. Yenkit eastern wadi - follow first sq 3 (then left) contact to east and continue to top.

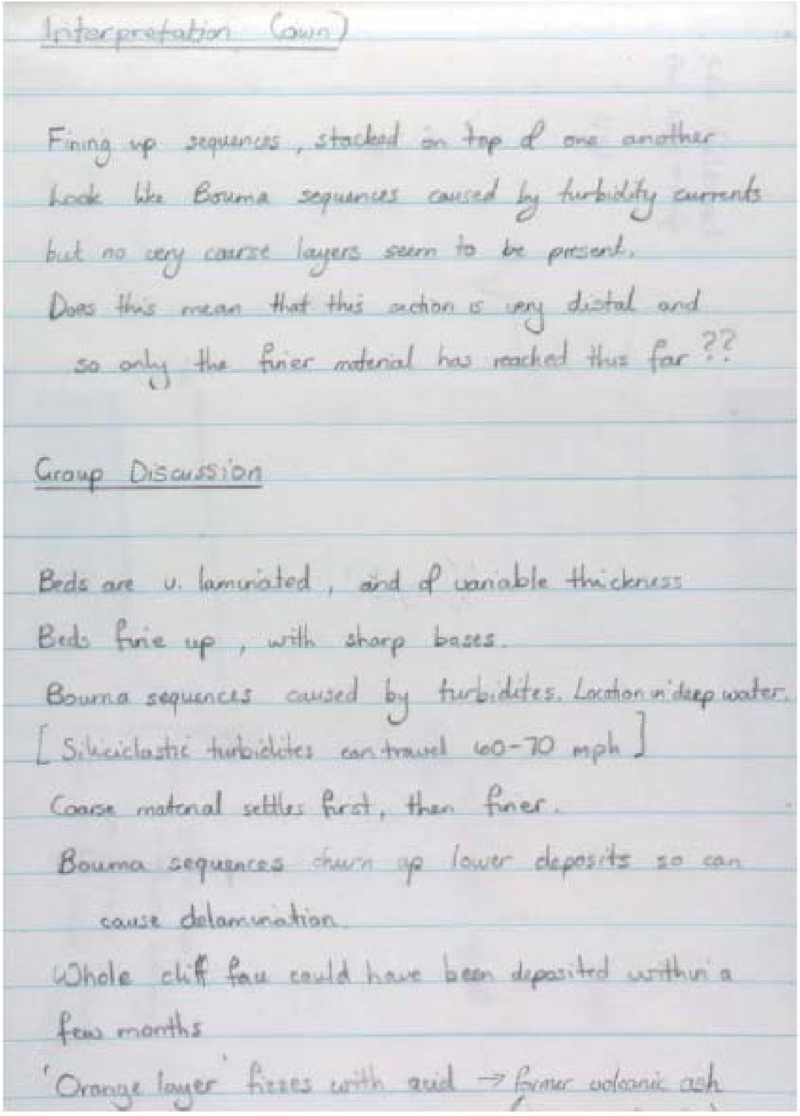
(b)

- Specimens List - 57

No	Locality	Grid Ref.	Remarks
KRL/90/1	2	103486	Oughterard granite (pink)
KRL/90/2	3	105438	Derrylaura Formation, Bot conglomerate.
KRL/90/3	10	085434	Oughterard granite. (greenish - white)
KRL/90/4	11	086437	"Flow-laminated", or rather very fractured green granite.
5	16	070420	Amphibolite with white feldspar alternations (+ vein?)
6	16	070420	Semi-pelite + quartzite + feldspathic psammite cut by a granite vein.
7	17	118438	Strophomenid shells and other brachiopods - orthids + probably spiriferids
8	17	118438	Shows way up, ∴ that most shells rest convex side up.

(c)

Figure 4.12 Extracts from field notebooks showing examples of checklists. (a) Tasks to be completed and possible timing. (Notebook of Tiffany Barry, The Open University, UK.) (b) Simple ' to do ' list. (Notebook of Clare Warren, The Open University, UK.) (c) Example of a rock sample list. (Notebook of Kate Bradshaw, The Open University, UK.)



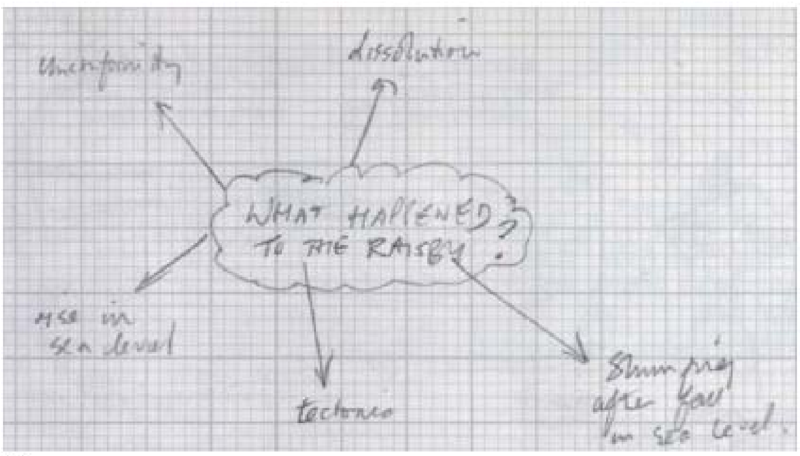
Interpretation (cont)

Fining up sequences, stacked on top of one another
Look like Bouma sequences caused by turbidity currents
but no very coarse layers seem to be present.
Does this mean that this section is very distal and
so only the finer material has reached thus far ??

Group Discussion

Beds are v. laminated, and of variable thickness
Beds fine up, with sharp bases.
Bouma sequences caused by turbidites. Location in deep water.
[Siliciclastic turbidites can travel 60-70 mph]
Coarse material settles first, then finer.
Bouma sequences churn up lower deposits so can
cause delamination
Whole cliff face could have been deposited within a
few months
'Orange layer' fizzes with acid → former volcanic ash

(a)



(b)

Figure 4.13 (a) Written interpretation in note form with clear indication of the source. (Notebook of Susan Ramsay, University of Glasgow, UK.) (b) Simple fi gure to summarize different interpretations of an observation. (Notebook of Brian McDonald, Open University student, UK.)

5.0 Photography

Photographs are a key part of most geological fieldwork. They can serve as an *aide memoire* , be used for image analysis, to document changes in an exposure over time and are also essential to illustrate key geological features in a report, talk or publication. As outlined is very important in the field not only to take a photograph but also to make field notes and sketches, because a photograph is *not* a replacement for a field sketch. A field sketch records how you have divided up the succession, provides a key to further notes and shows some geological interpretation. The photographs taken should be recorded in your field notebook and electronic information on the geological features and location added either through the camera or image processing software (Figure 12.1).
The detailed advantages and disadvantages of the wide range of cameras available on the market are outside of the scope of this book, so here we provide some general comments. Digital single - lens reflex (SLR) cameras provide the most amount of flexibility for a range of lighting conditions and types of photograph; they also generally have better lenses. However, many compact cameras give excellent results and have the added advantage that they are small and light. As with Personal Digital Assistants (PDAs), etc., check if the screen is visible under strong lighting conditions. This is essential when the camera does not have a view finder. If the camera does have a view finder but is not an SLR, the view finder does not usually give an exact representation of the frame of the photograph so you may need to work out exactly what that is if you wish to frame your subject exactly. Even with digital SLRs the view is not exactly the same. Cameras with good reviews for outdoor and scenic use will probably give the best geological field photographs. A good macro lens setting is advantageous if you are going to take a lot of close up photographs. In addition cameras that are sensitive to a wide range of lighting conditions allow maximum flexibility. There is almost no limit to the number of photographs you can take with a digital camera, provided that is you have enough

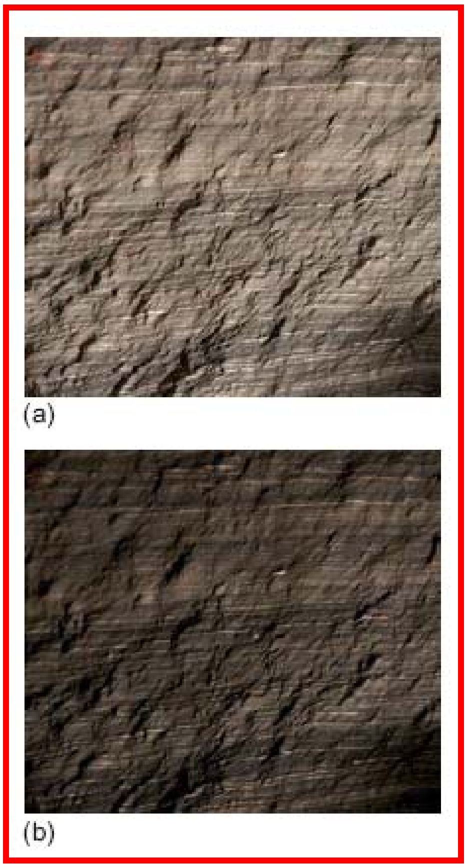


Figure 12.1 Two photographs taken under slightly different f – stops to illustrate the effect of varying the camera settings. Images are 40 cm high. (a) f 6.3 and (b) f 4.5. The associated metadata that it is useful to include in an electronic fi le are: camera type, shutter speed, f - stop, ISO setting, white balance (see Figure 12.2), focal length, date, time, place, subject, keywords. Some of this is recorded automatically and other parts such as the subject matter need to be added by the user. (a and b: Angela L. Coe, The OpenUniversity, UK.)

memory and battery capacity for the camera. This means you can take many more photographs than you will eventually use. The following tips may help give you a set of photographs that cover all eventualities.

• Make the first photograph at a locality a general view; this will remind you of where the photographs that follow on were taken.

• Take both general views and close - up views of different features.

• Take note of the lighting conditions. The best view under sunny conditions is often with the sun behind you, so this may mean returning to a locality at a different time of day to get the best lighting. Cloudy conditions provide a more even light, but sunny conditions can show some geological features better.

• If the lighting conditions are poor or variable take several shots with different settings. Note that underexposed digital photographs can be processed later to achieve a good image whereas overexposed photographs do not record all of the information. In Figure 12.1 , (b) is better than (a).

• The lighting late in the day and early in the morning (i.e. low - angle lighting) can bring out small - and medium – scale topographical features such as trace fossils and sedimentary structures.

• If you are using the photograph for image analysis ensure that it does not have any edge distortion, for instance that produced by using a wide - angle setting, or taking photos with the lens set to 50 mm or longer focal length. You will also need to take account of white balance under different lighting conditions (see manufacturer ' s instructions and Figure 12.2).

• Under low lighting conditions a tripod is useful; if you do not have a tripod with you try setting the camera up on a rock and using the self timer or a remote shutter release.

• If you are working where weather conditions are bad consider purchasing a waterproof camera case of the type used by divers for underwater photography.

• If you are taking a lot of photographs, for instance of shell beds or fine - scale detail, take the photographs in stratigraphic order to avoid confusion and consider marking the rocks in some manner, for instance with a marker pen, correction fluid or a tile scribe, so you know how the different photographs relate to each other. In most instances it is best if you stand perpendicular to the object being photographed.

• You can use the white pages of a notebook to reflect light into the shadowed portions of exposures, especially under overhangs.

• Include a scale or make a note of the size of the area being photographed. Depending on the subject of the photograph this could be anything from another person to a ruler, camera lens cap, coin or penknife. For small – scale photographs a finger is also useful and one of the advantages of this is that you will not inadvertently leave it behind! Ideally with medium and small objects use a metric scale rather than an object such as a lens cap or coin because these have variable dimensions. In addition the scale should preferably be of a neutral colour (grey) so that it will not unduly affect photographic exposure. Alternatively draw a scale on the cover of your notebook with a bold marker pen.

• When taking a photograph of an area you have sketched consider including the field notebook page in one corner of one of the photographs as a means of cross referencing between the photographs and your field notebook (assuming the field of view is appropriate).

• Use a page of your field notebook to point out or label particular features on the photograph.

• Assuming you are using a digital camera check, using the camera display screen, the exposure and as far as possible that the focus is OK before you leave the locality so that you can take another photograph if necessary.

6.0 Sampling

Sampling can be a crucial part of a field program because the samples, your field notes and photographs are all that you will have when you return from the field. But all too often sampling is rushed either because it is the last task completed or because of the perceived need to cover a wide area within a short time and extract material that is easily accessible. It is, however, well worth spending some time collecting samples and recording exactly where they are from, especially if you are going to complete many hours of laboratory work on them. Once collected, samples are often used for purposes other than those for which they were originally intended. The key points to consider when taking samples are:

- What are the objectives and therefore how much and what type of sample is required?
- Is the sample representative?
- What does the sampling resolution need to be?
- Is the sample fresh and un weathered? (Unless of course the study is about weathering.)
- Does the sample need to be orientated?
- Do I have the appropriate tools for the job?
- Have I recorded exactly where the sample is from?
- Is there a record of how the samples were collected, for instance the tools used (to eliminate possible contamination) and stratigraphic precision?
- What are the conservation issues? Am I taking only what is necessary, have I got the necessary permission and have I considered the visual impact on the environment?

6.1 Selecting and labeling samples

The size and nature of the sample required depend on the type of analyses that need to be performed. The appropriate vertical and horizontal sampling interval will depend upon the purpose of the study. Secondary to this consider the following: lithological variations, deposition rate, proximity to suspected boundaries, suspected or known repetition, resources and field constraints. This section outlines the factors to be taken into account depending on the intended purpose of the samples. Care needs to be taken to avoid cross - contamination when selecting samples for geochemical analysis, mineral analysis, microfossils, molecular fossils and high - resolution studies.

6.2 Samples for thin - sections

A sample of about 10 cm thick * 5 cm * 5 cm is usually sufficient for producing one or more thin - sections provided the rock is not too coarse - grained. If the rock is coarse - grained then a sample size that is appropriate to the grain size should be taken. The sample needs to be large enough to enable it to be clamped in the rock saw and care needs to be taken with sample position and shape if it needs to be orientated (see below). In deformed rocks it is useful to cut two or even three thin - sections at right angles to each other, so a slightly larger sample may be required.

6.3 Orientated samples Younging direction and approximately orientated samples

For sedimentary rocks the younging direction is often required and is usually recorded on the face perpendicular to bedding with an arrow. If the bedding orientation is not clear this may also need to be recorded so that the section can be cut perpendicular to the bedding. For igneous rocks the younging direction may need to be recorded for cumulates, pyroclastic rocks, and igneous rocks containing flow features and vesicles. For samples from metamorphic rocks it is also often necessary to record the top surface because of the need to obtain thin - sections in a particular orientation relative to the structural fabric(s). A more precise method of orientating samples is provided below.

6.4 Precisely orientated samples

Some samples need to be precisely orientated in the field so that this can be taken into account during later processing (Figure 13.1). This includes samples for palaeomagnetism studies and some samples for more precise metamorphic and structural analysis. To do this, find a piece of rock on the exposure that is going to be easily extractable, or if the rocks fracture in a manner that is suitable, extract the rock sample and then fi t it back into place exactly. Using a compass - clinometer mark the rock exactly with the line of strike, direction of dip and either the way up (Figure 13.1) or the top. Take note of the dip and strike. Orientated samples can also be obtained with a drill used for palaeomagnetic studies. This is a diamond - tipped tube of about 2 cm diameter. Samples are obtained by drilling the rock to obtain a cylinder of rock that is still attached at the back. This cylinder is then orientated using a modified compass - clinometer and wire to mark the corebefore it is extracted.

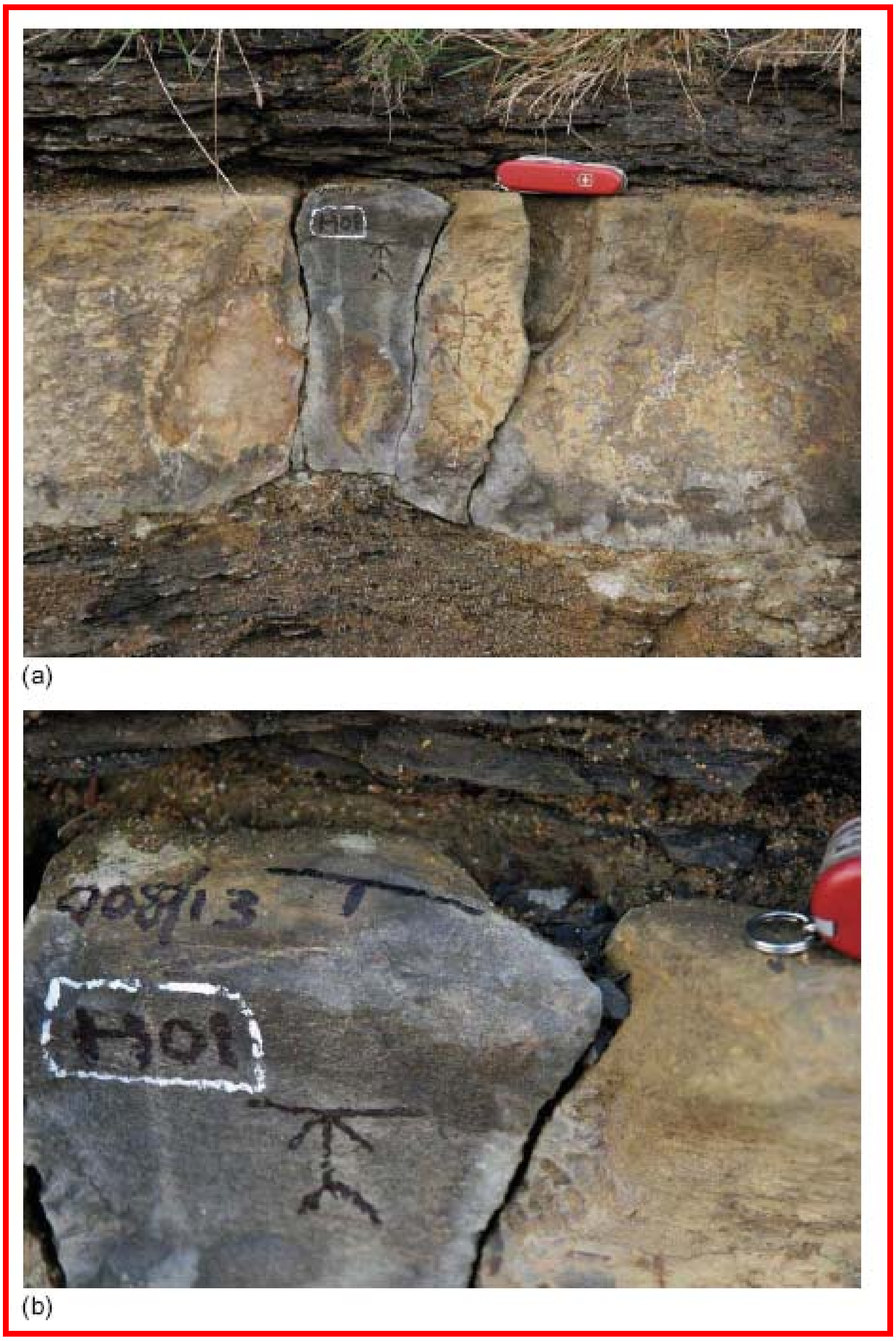


Figure 13.1 Orientated sample with combined strike line and direction of dip on the top surface and the sample number (H01) and way up (arrow) on the side. In this case part of the limestone that is fractured but nevertheless still intact and orientated has been chosen. Carboniferous strata, Rumbling Kern, Northumberland, UK. (a and b: Angela L. Coe, The Open University, UK.)

6.5 Samples for geochemical analysis

A 200 g sample is usually sufficient for a range of major and minor element, trace element and isotopic analyses, except for very coarse - grained or heterogeneous rocks, where about 1 kg may be required. Particular care needs to be taken to ensure that the sample is fresh. This might mean that weathered material needs to be removed first. If possible it is better to remove the weathered material in the field to ensure that what you take back is a fresh sample, and also because it is easier to allow for the extent of the weathering in the field. Colour changes are a good indication of weathering, but also the fracture pattern and hardness of the rock tend to change. In addition some rocks contain minerals that are the product of weathering (e.g. weathered mudstones often develop gypsum crystals). Some caution may also need to be exercised if the sample is being analyzed for metal isotopes in order to avoid contamination from metal chisels and hammers.

6.6 Samples for mineral extraction

The amount of sample that needs to be collected for mineral analysis depends on the minerals to be extracted and the composition of the rock. For heavy minerals such as zircon that are present only in low abundance, 1 – 2 kg of rock may be required. For volcanic glass and feldspars for $_{40}$Ar – $_{39}$Ar and K – Ar dating, generally at least 1 kg of rock is required. For pyroclastic and sedimentary rocks it is particularly important to collect from the base of the bed as the coarser – grained minerals that are more easily picked out will be most abundant there.

6.7 Samples for fossils

Samples for megafossil analysis: Megafossil samples and their supporting rock material tend to be large. They are best wrapped in paper. If they are fragile or the rock needs to dry out slowly, wrap them in cling film/plastic food wrap and then paper. They commonly have commercial value and therefore special permission may be needed to remove and/ or ship them out of the locality or country where they were collected. Important specimens should be donated to a museum after analysis and their sample (or museum acquisition) number referred to in any subsequent publication.

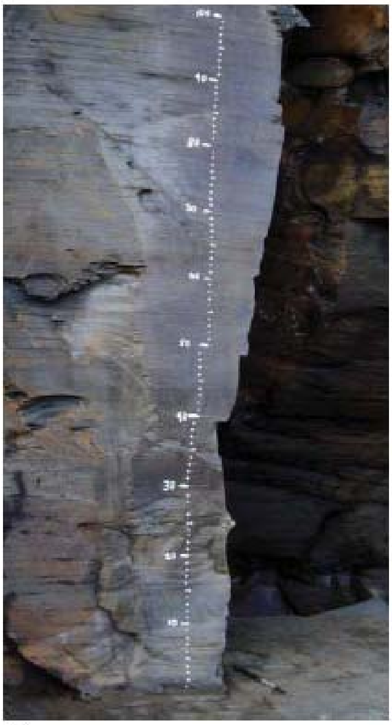
Samples for microfossil analysis: The size of samples for microfossil analysis depends on the likely abundance of fossils within the sample. For an average abundance of foraminifers 200 g should be sufficient; for nanofossils and diatoms a small 10 g sample is ample. For palynology samples of 0.5 – 1 kg are required. *Samples for molecular fossils:* Very small samples are required for molecular fossils but the sample needs to be large enough (2 – 5 g) to avoid contamination. The samples should be packaged in metal foil or glass or polythene bags of known composition. In addition care needs to be taken not to cross - contaminate samples by carefully cleaning the sampling instruments between each sample.

6.8 Sampling for regional studies

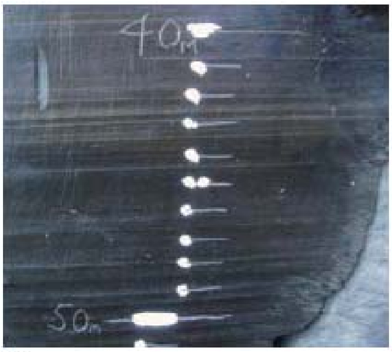
Regional and low - resolution studies require samples that are representative of the whole area. In addition samples should be collected from units that need laboratory analysis because their composition is enigmatic. It is difficult to generalize here though, as the sampling strategy will need to be adapted according to the hypothesis being tested. Collecting a sample from each of the main lithostratigraphic units is probably good place to start. If the region is fairly monolithic (for instance a large igneous province) then take regularly spaced samples that are spatially separated both horizontally and vertically, in addition to other key features such as potential feeder dykes. Other samples that are worth considering are a set to test for compositional variation across an igneous body, representative fossils, tectonic contacts, representative samples from metamorphic zones and representative samples from a set of dykes.

6.9 High - resolution sample sets

High - resolution sampling requires great care and patience. A logical means of labeling the samples/sample positions will need to be devised. In any situation where closely spaced samples are required it is best to mark the exposure clearly first with a scale (Figure 13.2) and, if irregularly spaced samples are required, mark where the samples will be taken from. The exposure can then be photographed as a permanent record before extracting the samples. Marking up the section can be done with a tile scribe, a marker pen, paint or paper correction



(a)



(b)

(c)

Figure 13.2 Marked sections ready for sampling. Lower Jurassic, Yorkshire, UK. (a) One stratigraphic meter of rock marked every 1 cm. (b) Detail section showing marks every 1 cm made with a tile scribe and correction fluid. Note in this case the letter ' m ' indicates minus as the marks are below the zero reference datum shown in (a). (c) Marking sections on both sides of a corner can be helpful when putting the section back together. (a – c: Christopher Pearce, The Open University, UK.)

6.10 Labeling samples and their packaging

It is worth spending some time devising a suitable labeling scheme for your samples. There are a variety of possibilities depending on the purpose of the study. For regional studies the locality number or an abbreviation of the name and then sample number at that locality is often used, e.g. 24/3 or FB/3, but an alternative way is to use the national grid square and then a sample number. The advantage of this is that the sample number gives an immediate indication of where it is from without the need to look at the fi eld notes. Another possibility is to include the date or part of the date in the sample number to allow you to easily find the associated field notes. For higher resolution studies where hundreds of samples are being collected a different strategy is often required. If the samples are at particular stratigraphic heights it can be useful to incorporate the height into the sample number. This makes handling of the numbers easier in spreadsheets at a later stage. An abbreviation for the age of the sample, e.g. S for Silurian, or for the lithostratigraphic name, e.g. BS for Burgess Shale, are other possibilities to consider including. On the sample itself, provided it is large enough and there is not going to be a contamination issue, it is useful to record the sample number and, if applicable, the way up and/or orientation. On the sample bag or outside of the packing material itself it is useful to record the following as appropriate:

- sample number;
- cross reference to field notebook page and/or date collected;
- location;
- whether or not the sample is orientated;
- rock type;
- associated samples.

6.11 Packing and marking materials

- *Cling film/shrink wrap:* This is very useful for fragile specimens such as fossils and mudstones. As well as the obvious advantage of helping to hold the specimen together the film also retains the moisture in the sample, allowing it to be dried out under controlled conditions.
- *Paper:* This is useful to help protect delicate specimens and for packing. It should not be used in direct contact with the rocks if the samples are also to be used for geochemical analysis, particularly organic carbon analyses.
- *Polythene sample bags:* It is good practice to put each sample into a new bag to avoid cross - contamination. Most bags come with write - on labels available from a variety of suppliers. Check for rocks with sharp edges because they tend to split the bag. If the rock has sharp edges either round them by gently tapping them using the square end of your hammer or carefully place the rock in a bag and wrap over this with paper.
- *Aluminium foil:* This is useful for holding together very fragile specimens such as mudstones. Wrap the foil around the specimen immediately after extraction in a systematic manner so that you are able to remove it sequentially in the laboratory.

Aluminium foil is best avoided if the samples will be stored for any length of time as salts from the rock tend to corrode the foil.

• *Glue:* A strong glue suitable for metal or wood can be used for sticking samples together. If you need to protect fragile specimens such as shelly material within mudstone or vertebrate teeth before shipping or transporting them back, soak the sample for several hours in a 50:50 mixture of PVA glue and water. Then allow the specimen to dry.

• *Marker pens:* Permanent marker pens provide a distinct label. Note that wet, dusty or fine - grained dark colored rocks can be difficult to mark. It is worth carrying several markers into the field because they tend to wear out quickly.

6.12 Extraction of samples

Different rocks break in different ways, but skill and experience enable the geologist to obtain the best samples. It is worth spending some time working out where to extract the best sample. Look for somewhere that is safe and easy to access and where there is a piece jutting out that might easily be removed. You should also consider the impact of extraction on the environment and preferably choose a location that will not be obvious. If you need just a small sample, tapping off the edge of the bed with the fl at end of the hammer usually works. <u>If you need a larger sample look for areas where there is already a line of weakness such as a bedding plane or joint</u>. This can often be widened and the rock weakened by hammering a cold chisel into the joint or bedding plane and then using leverage to extract the rock. For most fossils the rocks will need to be split along the bedding plane. <u>Some samples are hard to extract and it may take a lot of forceful blows with the hammer over time to weaken the rock. If you need a specific piece then use a chisel and work carefully around the sample</u>. You should chisel far enough away from the specific area that you need because there will always be some material lost close to where you chisel. When you have extracted the sample trim off any sharp corners. If you are extracting samples that need a way up it is a good idea to mark the way up first before you hammer it off just in case it is not possible to re orientate the sample after extraction.

Table A6.2 Features of common minerals that constitute sedimentary deposits.

Mineral	Chemical formula and name	Colour in hand specimen	Cleavage	Other features in hand specimen	Form and occurrence
Quartz	SiO_2 (silica)	Translucent	None	Will scratch steel	Common detrital grain, also a cement
Clay minerals	Various hydrous aluminosilicates	Typically grey, green or red	Planar or none	Fine-grained	
Calcite (sparite and micrite)*	$CaCO_3$ (calcium carbonate)	Translucent or white; variety of pale colours due to impurities	Rhombic	Scratched by steel; fresh surfaces fizz with acid	Forms grains, matrix and cement in limestones, dolomites and sandstones
Aragonite	$CaCO_3$ (calcium carbonate)	White with a pearly iridescence	Rectilinear	Original aragonitic bioclasts are often preserved in marine mudrocks	
Dolomite	$CaMg(CO_3)_2$ (calcium magnesium carbonate)	Buff, cream	Rhombic	Fizzes with warm acid and very weakly with cold acid	
Feldspar	Various including $K(Na)AlSi_3O_8$ (orthoclase) and $Na(Ca)\ AlSi_3O_8$ (albite)	Transluscent or pink or white	Present	Scratched by steel; weathers to white, powdery clay minerals	Detrital crystals
Glauconite	$KMg(Fe,Al)(SiO_3)_6.3H_2O$	Green	Planar	Soft; weathers to the iron oxide limonite	Ooids, mud and peloids; forms exclusively in marine environments
Iron oxide	Various including Fe_2O_3 (haematite) and $H_2Fe_2O_4(H_2O)_x$ (limonite)	Red (haematite) or yellow-brown (limonite) or green	None	Often more apparent on weathered surfaces	Crystals, grains, cements and as replacements